Attachment D

Regulatory and Human Health Benchmarks Used for Radionuclide SSL Development

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D.1 Current Radionuclide Slope Factors

The slope factors listed in Table D.1 are taken from the Health Effects Assessment Summary Tables (HEAST) which may be found on the internet at the following address: http://www.epa.gov/superfund/programs/risk/calctool.htm. The slope factors are derived primarily from *Health Risks from Low-Level Environmental Exposure to Radionuclides, Federal Guidance Report No. 13, Part I* - , U.S. EPA, 1999 (also known as FGR13). Table D.1 lists cancer slope factors for each route of intake for principal radionuclides in units of picocuries (pCi).[1] Radionuclides are presented alphabetically by element.

Selected radionuclides and radioactive decay chain products are designated with the suffix "+D" (e.g., U-238+D, Ra-226+D, Cs-137+D) to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment. Decay chains are identified in Attachment C, Table C.1.

In most cases, site-specific analytical data should be used to establish the actual degree of equilibrium between each parent radionuclide and its decay products in each media sampled. However, in the absence of empirical data, the "+D" values for radionuclides should be used unless there are compelling reasons not to.

Note that there may be circumstances, such as long disposal times or technologically enhanced concentrations of naturally occurring radionuclides, that may necessitate the combination of the risks of a parent radionuclide and its decay products over several contiguous subchains. For example, Ra-226 soil analyses at a site might show that all radium decay products are present in secular equilibrium down to stable Pb-206. In this case, Ra-226 risk calculations should be based on the ingestion, inhalation and external exposure slope factors for the Ra-226+D subchain, plus the ingestion, inhalation and external exposure factors for the Pb-210+D subchain. For actual sites, users should consult with a health physicist or radiochemist (1) to evaluate the site-specific analytical data to determine the degree of equilibrium between parent radionuclides and decay members of contiguous decay chains and (2) to assist in the combination of appropriate slope factor values.

[1] Slope factors are reported in the customary units of picocuries (1 pCi = 10^{-12} curies (Ci) = 3.7×10^{-2} nuclear transformations per second) for consistency with the system used for radionuclides in the IRIS database. If required, slope factors in Table 4 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by multiplying each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water and soil concentration values in the same system of units.

Table D.1 Radionuclide Cancer Morbidity - Slope Factors (1)

Radionuclide	Slope Factor (Morbidity Risk Coefficient) Lifetime Excess Cancer Risk per Unit Exposure					
	Water Ingestion (risk/pCi)	Food Ingestion (risk/pCi)	Soil Ingestion (risk/pCi)	Inhalation (risk/pCi)	External Exposure (risk/yr per PCi/g soil)	Notes
Ac-227+D	4.86E-10	6.53E-10	1.16E-09	2.09E-07	1.47E-06	2
Ag-108m+D	8.14E-12	1.12E-11	1.92E-11	2.67E-11	7.19E-06	2
Ag-110m+D	9.88E-12	1.37E-11	2.37E-11	2.83E-11	1.30E-05	2
Am-241	1.04E-10	1.34E-10	2.17E-10	2.81E-08	2.76E-08	
Am-243+D	1.08E-10	1.42E-10	2.32E-10	2.70E-08	6.36E-07	2
Bi-207	5.66E-12	8.14E-12	1.49E-11	2.10E-11	7.08E-06	
C-14	1.55E-12	2.00E-12	2.79E-12	7.07E-12	7.83E-12	3
Cd-109	5.00E-12	6.70E-12	1.14E-11	2.19E-11	8.73E-09	
Ce-144+D	3.53E-11	5.19E-11	1.02E-10	1.10E-10	2.44E-07	2
Cl-36	3.30E-12	4.44E-12	7.66E-12	2.50E-11	1.74E-09	
Cm-243	9.47E-11	1.23E-10	2.05E-10	2.69E-08	4.19E-07	
Cm-244	8.36E-11	1.08E-10	1.81E-10	2.53E-08	4.85E-11	
Co-57	1.04E-12	1.49E-12	2.78E-12	2.09E-12	3.55E-07	
Co-60	1.57E-11	2.23E-11	4.03E-11	3.58E-11	1.24E-05	
Cs-134	4.22E-11	5.14E-11	5.81E-11	1.65E-11	7.10E-06	
Cs-135	4.74E-12	5.88E-12	7.18E-12	1.86E-12	2.36E-11	
Cs-137+D	3.04E-11	3.74E-11	4.33E-11	1.19E-11	2.55E-06	2
Eu-152	6.07E-12	8.70E-12	1.62E-11	9.10E-11	5.30E-06	
Eu-154	1.03E-11	1.49E-11	2.85E-11	1.15E-10	5.83E-06	
Eu-155	1.90E-12	2.77E-12	5.40E-12	1.48E-11	1.24E-07	
Fe-55	8.62E-13	1.16E-12	2.09E-12	7.99E-13	0	
Gd-153	1.52E-12	2.22E-12	4.26E-12	6.55E-12	1.62E-07	
H-3	5.07E-14	6.51E-14	9.25E-14	5.62E-14	0	4
I-129	1.48E-10	3.22E-10	2.71E-10	6.07E-11	6.10E-09	5
K-40	2.47E-11	3.43E-11	6.18E-11	1.03E-11	7.97E-07	
Mn-54	2.28E-12	3.11E-12	5.14E-12	5.88E-12	3.89E-06	
Na-22	9.62E-12	1.26E-11	1.97E-11	3.89E-12	1.03E-05	
Nb-94	7.77E-12	1.11E-11	2.05E-11	3.77E-11	7.29E-06	
Ni-59	2.74E-13	3.89E-13	7.33E-13	4.66E-13	0	
Ni-63	6.70E-13	9.51E-13	1.79E-12	1.64E-12	0	
Np-237+D	6.74E-11	9.10E-11	1.62E-10	1.77E-08	7.97E-07	2
Pa-231	1.73E-10	2.26E-10	3.74E-10	4.55E-08	1.39E-07	
Pb-210+D	1.27E-09	3.44E-09	2.66E-09	1.39E-08	4.21E-09	2
Pm-147	1.69E-12	2.48E-12	4.88E-12	1.61E-11	3.21E-11	
Pu-238	1.31E-10	1.69E-10	2.72E-10	3.36E-08	7.22E-11	
Pu-239	1.35E-10	1.74E-10	2.76E-10	3.33E-08	2.00E-10	
Pu-240	1.35E-10	1.74E-10	2.77E-10	3.33E-08	6.98E-11	
Pu-241	1.76E-12	2.28E-12	3.29E-12	3.34E-10	4.11E-12	
Pu-242	1.28E-10	1.65E-10	2.63E-10	3.13E-08	6.25E-11	
Pu-244+D	1.44E-10	1.90E-10	3.14E-10	2.93E-08	1.51E-06	2
Ra-226+D	3.86E-10	5.15E-10	7.30E-10	1.16E-08	8.49E-06	2
Ra-228+D	1.04E-09	1.43E-09	2.29E-09	5.23E-09	4.53E-06	2
Ru-106+D	4.22E-11	6.11E-11	1.19E-10	1.02E-10	9.66E-07	2
Sb-125+D	5.13E-12	7.21E-12	1.32E-11	1.93E-11	1.81E-06	2
Sm-147	3.74E-11	4.77E-11	7.59E-11	6.88E-09	0	
Sm-151	5.55E-13	8.07E-13	1.59E-12	4.88E-12	3.60E-13	
Sr-90+D	7.40E-11	9.53E-11	1.44E-10	1.13E-10	1.96E-08	2
Tc-99	2.75E-12	4.00E-12	7.66E-12	1.41E-11	8.14E-11	
Th-228+D	3.00E-10	4.22E-10	8.09E-10	1.43E-07	7.76E-06	2
Th-229+D	5.28E-10	7.16E-10	1.29E-09	2.25E-07	1.17E-06	2
Th-230	9.10E-11	1.19E-10	2.02E-10	2.85E-08	8.19E-10	
Th-232	1.01E-10	1.33E-10	2.31E-10	4.33E-08	3.42E-10	
Tl-204	5.85E-12	8.25E-12	1.54E-11	2.45E-12	2.76E-09	
U-232	2.92E-10	3.85E-10	5.74E-10	1.95E-08	5.98E-10	
U-233	7.18E-11	9.69E-11	1.60E-10	1.16E-08	9.82E-10	
U-234	7.07E-11	9.55E-11	1.58E-10	1.14E-08	2.52E-10	
U-235+D	7.18E-11	9.76E-11	1.63E-11	1.01E-08	5.43E-07	2
U-236	6.70E-11	9.03E-11	1.49E-10	1.05E-08	1.25E-10	
U-238+D	8.71E-11	1.21E-10	2.10E-10	9.35E-09	1.14E-07	2

Radionuclide	Water Ingestion (risk/pCi)	Food Ingestion (risk/pCi)	Soil Ingestion (risk/pCi)	Inhalation (risk/pCi)	External Exposure (risk/yr per PCi/g soil)	Notes
Zn-65	1.17E-11	1.54E-11	2.45E-11	5.81E-12	2.81E-06	

Notes:

1. A curie (Ci), the customary unit of activity, is equal to 3.7×10^{10} nuclear transformations per second. 1 picocurie (pCi) = 10^{-12} Ci. If required, slope factors in Table D.1 can be converted into the International System (SI) units of becquerels (1 Bq = 1 nuclear transformation per second) by multiplying each inhalation, ingestion, or external exposure value by 27.03. Users can calculate cancer risks using slope factors expressed in either customary units or SI units with equivalent results, provided that they also use air, water, food and soil concentration values in the same system of units.

2. For each radionuclide listed, slope factors correspond to the risks per unit intake or exposure for that radionuclide only, except when marked with a "+D". In these cases, the risks from associated short-lived radioactive decay products (i.e., those decay products with radioactive half-lives less than or equal to 6 months) are also included, based on an assumption of secular equilibrium. These decay chains are identified in Table C.1 of Attachment C.

3. The inhalation slope factor listed represents inhalation of C-14 as a particulate. Alternative values for inhalation of C-14 as a gas are 3.36E-15 risk/pCi for carbon monoxide and 1.99E-14 risk/pCi for carbon dioxide.

4. The inhalation slope factor for H-3 represents inhalation of titiated water vapor, which is considered the most likely form in the environment. Alternative values of inhalation of H-3 include 1.99E-13 risk/pCi for particulates, 5.62E-18 risk/pCi for elemental hydrogen gas, and 1.28E-13 risk/pCi for organic forms. Similarly, the ingestion slope factor values for H-3 represent ingestion of tritiated water, which is considered the most likely form in the environment. Alternative values for ingestion of organically bound forms of H-3 in water, food, and soil are 1.12E-13 risk/pCi, 1.44E-13 risk/pCi, and 2.02E-13 risk/pCi, respectively.

5. The food ingestion slope factor for I-129 represents ingestion of milk. For ingestion of non-dairy foodstuffs, a lower value of 1.93E-10 risk/pCi ingested would apply. The inhalation slope factor for I-129 represents inhalation of particulates; alternative values for inhalation of I-129 vapor are 1.24E-10 for inhalation of methyl iodide and 1.60E-10 for inhalation of other compounds in vapor form.

D.2 MCLs for Radionuclides in Drinking Water

Current MCLs for radionuclides are set at 4 mrem/yr for the sum of the doses from beta particles and photon emitters, 15 pCi/L for gross alpha particle activity (including Ra-226, but excluding uranium and radon), and 5 pCi/L combined for Ra-226 and Ra-228. The current MCLs for beta emitters specify that MCLs are to be calculated based upon an annual dose equivalent of 4 mrem to the total body or any internal organ. It is further specified that the calculation is to be performed on the basis of a 2 liter per day drinking water intake using the 168 hours data listed in "*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure,"* NBS Handbook 69 as amended August 1963, U.S. Department of Commerce (U.S. DOC, 1963). These calculations have been done for most beta emitters and published as part of the EPA Office of Water Supply's National Interim Primary Drinking Water Regulations, Report EPA-570/9-76-003 (U.S, EPA, 1976). The calculated MCLs are included in Table D.2. For those beta emitters not included in EPA-570/9-76-00, MCLs have been calculated, for purposes of this guidance, using the existing MCL methodology, and are also included in Table D.2.

In July 1991, EPA proposed to revise the MCLs for Ra-226 and Ra-228 to 20 pCi/L for each, change the methodology used for determining a 4 mrem/yr dose for the sum of the doses from beta particles and photon emitters, alter the definition of alpha particle activity to exclude Ra-226, and establishing new MCLs of 300 pCi/L for Rn-222 and 20 µg/L (30 pCi/L) for uranium (56 FR 33050). EPA is under Court Order to either finalize the 1991 proposal for radionuclides (except for radon), or to ratify existing standards by November 2000. On April 21, 2000 EPA solicited comment in a Notice of Data Availability (NODA) on three options for a uranium MCL: 1) 20 μg/l **and** 20 pCi/l as a preferred option, 2) 40 μg/l **and** 40 pCi/l, and 3) 80 μg/l **and** 80 pCi/l (65 FR 21576). In this NODA, EPA indicated that changes would not be made to the existing MCLs for radium, alpha particle activity, and beta particles and photon emitters. The 1996 Amendments to the Safe Drinking Water Act (SDWA) require EPA to propose a MCL for radon by August 1999, and to finalize the MCL by August 2000. To comply with the requirements of the amended SDWA, on August 6, 1997, EPA withdrew its 1991 proposal for Rn-222 (62 FR 42221). EPA issued a new proposal for Rn-222 (65 FR 21576). EPA proposed an MCL of 300 pCi/l with an alternative MCL of 4,000 pCi/l if a state or local indoor radon mitigation program was established.

Table D.2 Radionuclide Drinking Water MCLs

Radionuclide	Current MCL[a, b] (pCi/L)	Proposed MCL (pCi/L)	Risk Base Limit (RBL)[e] (pCi/L)	Mass Equiv to MCL, Proposed MCL, or RBL (mg/L)
Ac-227			0.24	3.3E-12
Ag-108m			5.8	2.2E-10
Ag-110m	90			1.9E-11
Am-241	15			4.4E-09
Am-243	15			7.5E-08
Bi-207	200			4.4E-09
C-14	2,000			4.5E-07
Cd-109	600			2.3E-10
Ce-144	30			9.1E-12
Cl-36	700			2.1E-05
Cm-243	15			2.9E-10
Cm-244	15			1.9E-10
Cm-248	15			3.5E-06
Co-57	1,000			1.2E-10
Co-60	100			8.9E-11
Cs-134	80			6.2E-11
Cs-135	900			7.8E-04
Cs-137	200			2.3E-09
Eu-152	200			1.1E-09
Eu-154	60			2.3E-10
Eu-155	600			1.3E-09
Fe-55	2,000			8.3E-10
Gd-153	600			1.7E-10
H-3	20,000			2.1E-09
I-129	1			5.7E-06
K-40			1.9	2.7E-4
Mn-54	300			3.9E-11
Na-22	400			6.4E-11
Nb-94			6.1	3.3E-8
Ni-59	300			3.7E-06
Ni-63	50			8.5E-10
Np-237	15			2.1E-05
Pa-231	15			3.2E-07
Pb-210			0.054	7.1E-13
Pm-147	587			6.3E-10
Pu-238	15			8.8E-10

Table D.2 Radionuclide Drinking Water MCLs

Radionuclide	Current MCL[a, b] (pCi/L)	Proposed MCL (pCi/L)	Risk Base Limit (RBL)[e] (pCi/L)	Mass Equiv to MCL, Proposed MCL, or RBL (mg/L)
Pu-239	15			2.4E-07
Pu-240	15			6.6E-08
Pu-241			27	2.6E-10
Pu-242	15			3.8E-06
Pu-244	15			8.5E-04
Ra-226	5[c]			5.1E-09
Ra-228	5[c]			1.8E-11
Ru-106	30			9.0E-12
Sb-125	300			2.9E-10
Sm-147	15			6.5E-01
Sm-151	1,000			3.8E-08
Sr-90	8			5.9E-11
Tc-99	900			5.3E-05
Th-228	15			1.8E-11
Th-229	15			7.1E-08
Th-230	15			7.4E-07
Th-232	15			1.4E-01
Tl-204	300			6.5E-10
U-232		20[d]		9.4E-10
U-232		(20 μg/l)[d]		2.0E-02
U-233		20[d]		2.1E-06
U-233		(20 μg/l)[d]		2.0E-02
U-234		20[d]		3.2E-06
U-234		(20 μg/l)[d]		2.0E-02
U-235		20[d]		9.3E-03
U-235		(20 μg/l)[d]		2.0E-02
U-236		20[d]		3.1E-04
U-236		(20 μg/l)[d]		2.0E-02
U-238		20[d]		6.0E-02
U-238		(20 μg/l)[d]		2.0E-02
Zn-65	300			3.6E-11

Notes:

[a] Existing MCL is 4 mrem/yr to the whole body or an organ, combined from all beta and photon emitters.

[b] Existing MCL is 15 pCi/L, with the concentration level combined for all alpha emitters, except radon and uranium.

[c] Existing MCL is 5 pCi/L combined for Ra-226 and Ra-228.

[d] Preferred EPA proposed MCL standard is 20 μg/l and 20 pCi/l for uranium, with EPA soliciting comments on options of 40 μg/l **and** 40 pCi/l, and 80 μg/l **and** 80 pCi/l. The preferred proposed MCL standard for uranium of 20 μg/l and 20 pCi/l is represented in this table.

[e] Risk Based Limits calculated for 30-year exposure duration and 10^{-6} risk. These were calculated using equation 11′ in *Risk Assessment Guidance for Superfund* (RAGS)*: Volume i: Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)*, (page 37). The equations were adjusted to account for radioactive decay.